

AIRS stratospheric temperature retrievals at full horizontal resolution

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1 **Motivation**

Why do we need temperature data at full horizontal resolution?

2 **Forward modelling for AIRS**

Brief description of the JURASSIC forward model.

Model optimization and validation.

3 **Stratospheric temperature retrievals**

Brief description of the optimal estimation approach.

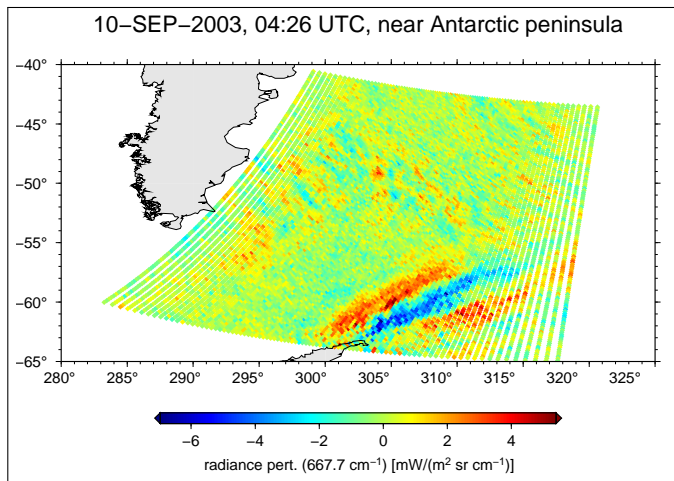
Retrieval parameter studies and characteristics.

4 **First results and summary**

Retrieved temperature data for selected AIRS granules.

Motivation

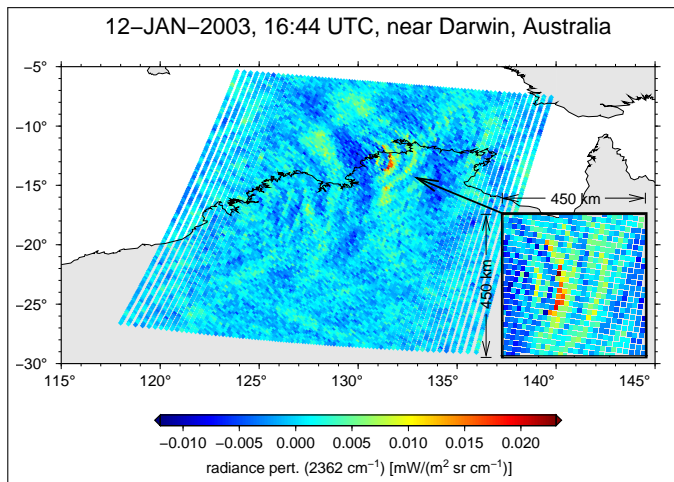
AIRS radiance measurements provide information about stratospheric gravity waves on small horizontal scales...



(Typical horizontal wavelength in this area: $\lambda_x \sim 100 \text{ km}$)

Motivation

Example of gravity waves produced by deep convection...



⇒ Loss of horizontal resolution in operational temperature retrieval (20 km → 60 km; cloud-clearing) is a drawback for gravity wave studies...

Forward Modelling for AIRS

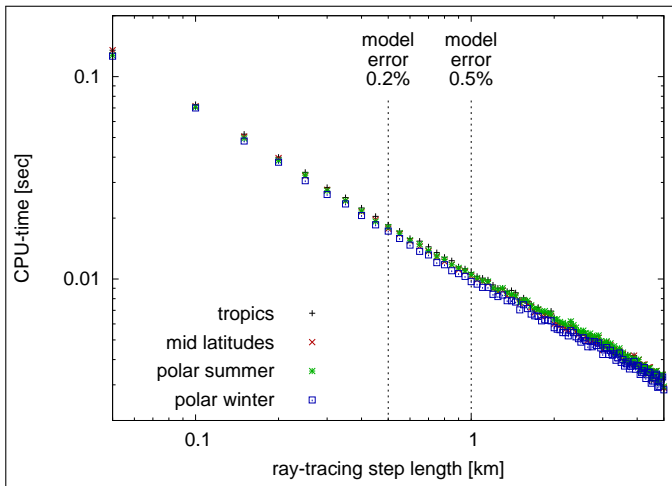
- Juelich Rapid Spectral Simulation Code (**JURASSIC**)
- **Fast radiative transfer model** for the mid-infrared spectral region (4...15 micron, LTE, no scattering, no surface).
- **Approximations** for fast radiative transfer calculations:
 - Band Transmittance Approximation
 - Emissivity Growth Approximation
 - Independent Gas Approximation
 - Look-up tables for spectral mean emissivity
- Flexible handling of different types of **observation geometry** and **atmospheric data**:
 - Interpolation of 1D, 2D or 3D atmospheric data (single profiles, satellite track, model output)
 - Observer within or outside atmosphere
 - Nadir, sub-limb, limb or zenith viewing

Forward Modelling for AIRS

- **Modelling of instrument effects:**
 - Spectral filter functions (ILS, SRF,...)
 - Vertical field of view (FOV)
 - Offset and gain calibration
- **Retrieval interface:**
 - Definition of state and measurement vector ($\mathbf{x}, \mathbf{b}, \mathbf{y}$)
 - Jacobians by numerical perturbation ($z, p, T, q_i, k_j, c_0, c_1$)
- **Optimization studies and validation studies:**
 - Optimized ray-tracing step length
 - Optimized emissivity look-up tables
 - Comparisons against MIPAS RFM
 - Comparisons against AIRS SARTA
- Documentation and download:
<https://jurassic.icg.kfa-juelich.de>

Forward Modelling for AIRS

Optimization of ray-tracing step size...

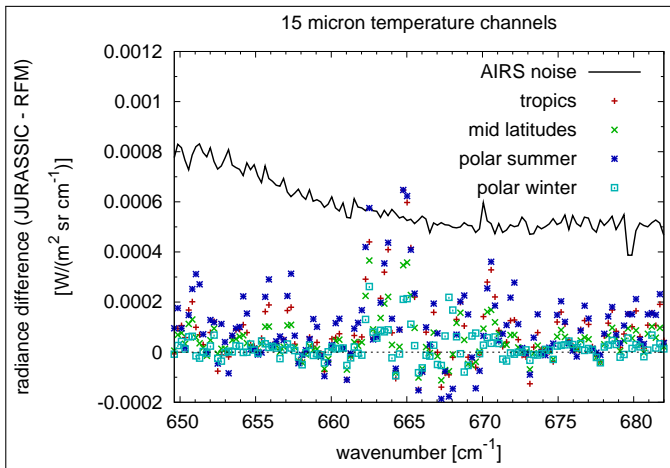


⇒ CPU-time for forward calculation is about 20 msec on a normal PC.

Reduction by a factor 1000 compared to line-by-line reference calculations.

Forward Modelling for AIRS

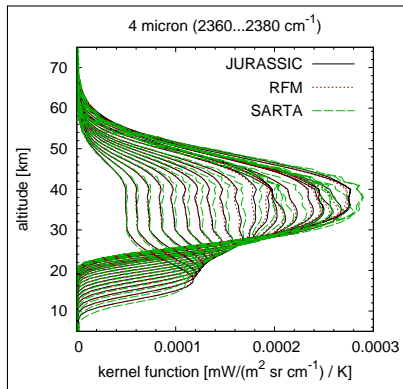
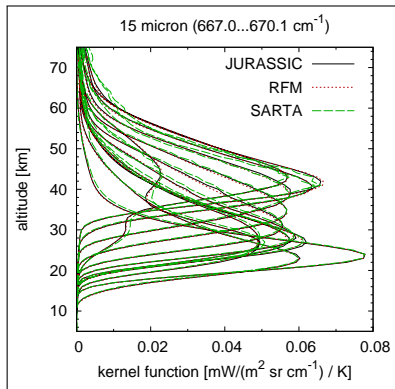
Comparison of JURASSIC and RFM...



⇒ Reference model output is reproduced within AIRS noise.

Results for 4 micron channels are similar.

Comparison of temperature kernel functions...



⇒ Good agreement! 4 micron kernels are rather broad (due to broad SRFs),
i. e. provide less information on vertical distribution, but help to reduce noise.

Stratospheric Temperature Retrievals

- **Optimal estimation approach:** Find optimal estimate (i. e. MAP solution) of retrieval targets \mathbf{x} for given measurements \mathbf{y} by minimizing a cost function:

$$J(\mathbf{x}) = \underbrace{[\mathbf{y} - \mathbf{F}(\mathbf{x})]^T \mathbf{S}_\epsilon^{-1} [\mathbf{y} - \mathbf{F}(\mathbf{x})]}_{\text{measurements - forward calculation}} + \underbrace{(\mathbf{x} - \mathbf{x}_a)^T \mathbf{S}_a^{-1} (\mathbf{x} - \mathbf{x}_a)}_{\text{atmospheric state - a priori}}$$

\mathbf{x} = atmospheric state

\mathbf{y} = radiance measurements

\mathbf{S}_ϵ = measurement error covariance

$\mathbf{F}(\mathbf{x})$ = simulated observations (forward model)

\mathbf{x}_a = a priori state

\mathbf{S}_a = a priori covariance

Stratospheric Temperature Retrievals

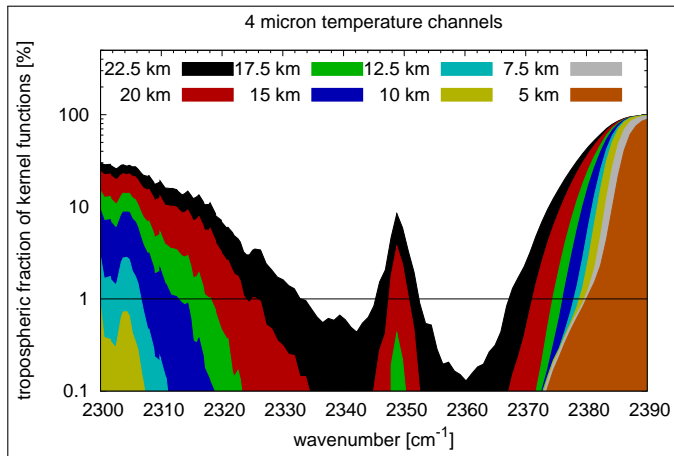
- **Retrieval grid:**
 - 1D case: homogeneously stratified atmosphere
 - Fixed altitudes: 3 km below 60 km, 5 km up to 90 km
 - Retrieve only T, get p from hydrostatic equilibrium.
- **Measurement error covariance:**
 - Consider only noise (uncorrelated).
- **A priori data:**
 - Use AIRS operational retrieval results as a priori state (inter/extrapolate data gaps).
 - Use a priori uncertainty of $\sigma_i = 20$ K, correlations from first-order autoregressive model:

$$S_{ij} = \sigma_i \sigma_j \exp(-\Delta z / c_z)$$

Correlation length c_z is an important tuning parameter!

Stratospheric Temperature Retrievals

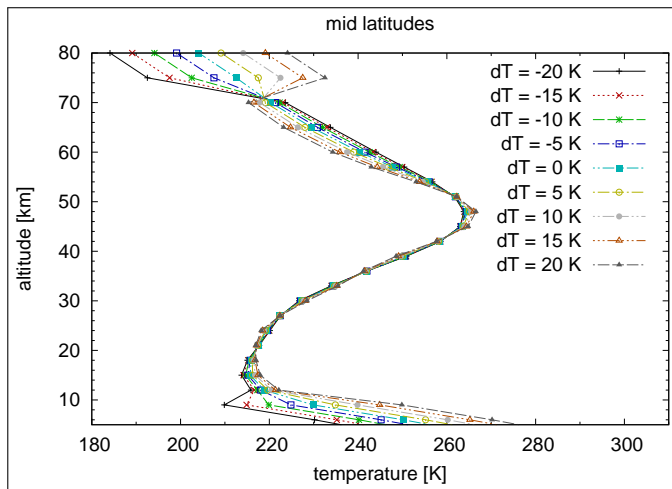
Selection of AIRS channels for the retrieval...



⇒ Exclude all channels where tropospheric fraction of kernel functions ($z_{\text{trop}} = 17.5 \text{ km}$) exceeds 1% to minimize influence of clouds...

Stratospheric Temperature Retrievals

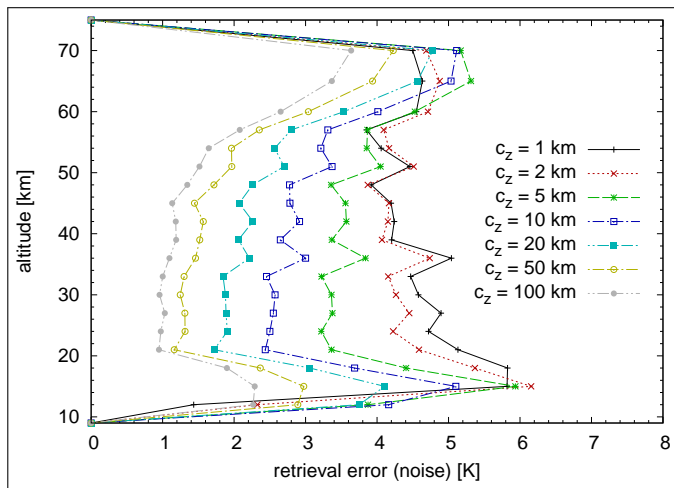
Influence of a priori data...



⇒ Varying the a priori profile by ± 20 K causes differences below ± 1.5 K in the retrieved profile at 20 ... 55 km altitude.

Stratospheric Temperature Retrievals

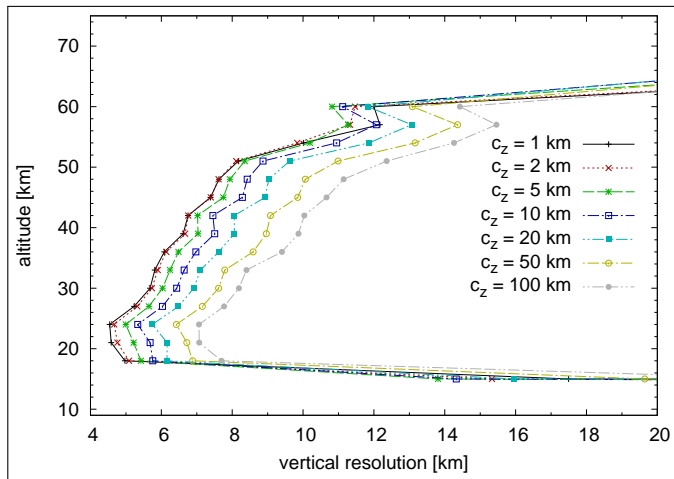
Retrieval error due to noise...



⇒ We use an a priori vertical correlation length of 50 km to reduce the retrieval error due to noise: The resulting error is 1 ... 2 K at 20 ... 55 km.

Stratospheric Temperature Retrievals

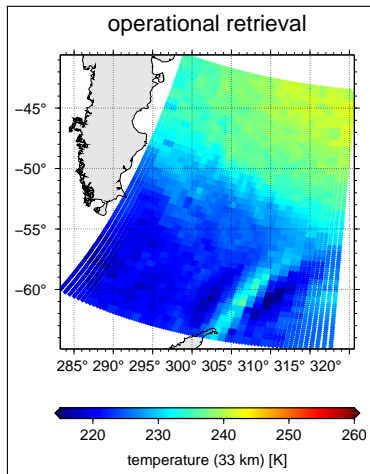
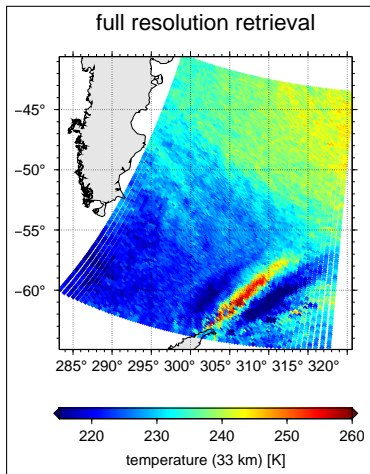
Vertical resolution...



⇒ For 50 km a priori vertical correlation length the vertical resolution is 7 ... 11 km at 20 ... 55 km.

Full Resolution Temperature Data – First results

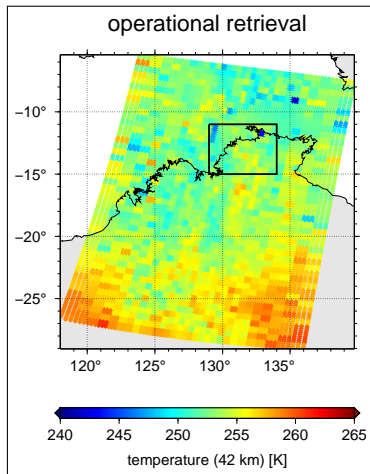
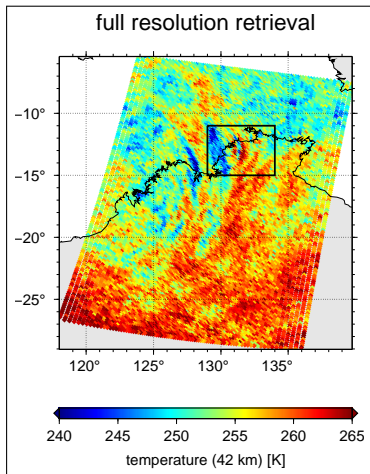
Gravity waves near Antarctic peninsula...



⇒ Full resolution retrieval results resemble operational data,
but gravity wave amplitudes are larger.

Full Resolution Temperature Data – First results

Gravity waves produced by deep convection...



⇒ Retrieval at full horizontal resolution reveals small-scale structures!

Warm bias (about 3 ... 5 K) in full resolution retrievals at the stratopause.

Summary

- We use the **fast radiative transfer model JURASSIC** to simulate AIRS measurements:
 - The fast model helps to reduce CPU-time by a factor 1000.
 - Reference calculations are reproduced within AIRS noise.
- We use the **optimal estimation approach** to retrieve temperature data for the stratosphere:
 - Altitude Range: 20 ... 55 km
 - Vertical resolution: 7 ... 11 km (about 6 dfs)
 - A priori information: less than 5%
 - Retrieval error (due to noise): 1 ... 2 K
- First retrieval results for selected granules look promising: The full resolution data much better reveal the **horizontal small-scale structures** caused by gravity waves.